

Los Alamos National Laboratory

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NATIONAL SECURITY SCIENCE

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EXPLOSION (N.):

**A LOUD NOISE AND THE
SUDDEN GOING AWAY OF
THINGS FROM THE PLACE
WHERE THEY HAVE BEEN**

*~The Chemistry of Powder & Explosives
by Tenney L. Davis*

To test whether a travel-toothpaste-tube-sized bomb could bring down an airliner, Los Alamos scientists tried to blow a hole through half-inch-thick aircraft-grade aluminum using an explosive they developed. As seen by the approximately 5-inch hole in the blast plate pictured at left, their efforts were successful. (Photo: Los Alamos)

EXPLOSIVE RESULTS

LOS ALAMOS LEADS EXPLOSIVES-SCIENCE RESEARCH

Scientists at Los Alamos are solving national security challenges, from the threat of toothpaste bombs on airliners to ensuring the safety of our nuclear stockpile.

In February 2014, the U.S. Department of Homeland Security (DHS) got wind of a potential new bomb threat: explosives packed into a toothpaste tube that a terrorist planned to smuggle onto an airplane headed for the Winter Olympics at Sochi, Russia.

Could someone make such a small bomb and blow an airliner full of passengers out of the sky?

With no time to waste, scientists in the Explosive Science and Shock Physics division at Los Alamos National Laboratory leapt into action. In approximately 24 hours they tested an explosive they developed and called back with the answer: Yes, a toothpaste bomb was possible—“very possible,” in the words of Lab explosives researcher Bryce Tappan, who responded to the inquiry. And it could bring down an airliner.

Ever since the Manhattan Project, maintaining the safety, security, and reliability of the nation’s nuclear stockpile has driven multidisciplinary explosives research at Los Alamos.

Understanding the nature of the toothpaste-bomb threat was a “how-do-you-make-it?” problem. That kind of explosives research is just one piece of the Lab’s A-to-Z range of capabilities, most of them interrelated and synergistic and necessary to solve challenges to U.S. national security. As Tappan points out, Los Alamos has more scientists studying things that go *kaboom!* than anyplace in America and quite possibly the world.

That’s why national security and defense experts turn to Los Alamos. The Laboratory has been blowing up materials and studying the results for a long time. Los Alamos burst into the public consciousness 70 years ago with the biggest explosion known to humanity—the world’s first atomic bomb. That breakthrough required Manhattan Project scientists to understand the behavior of the conventional explosives that detonated a nuclear weapon, particularly in developing the uniquely shaped charges necessary to create a critical mass of plutonium in the implosion bomb design. Ever since the Manhattan Project, maintaining the safety, security, and reliability of the nation’s nuclear stockpile has driven multidisciplinary explosives research at Los Alamos.

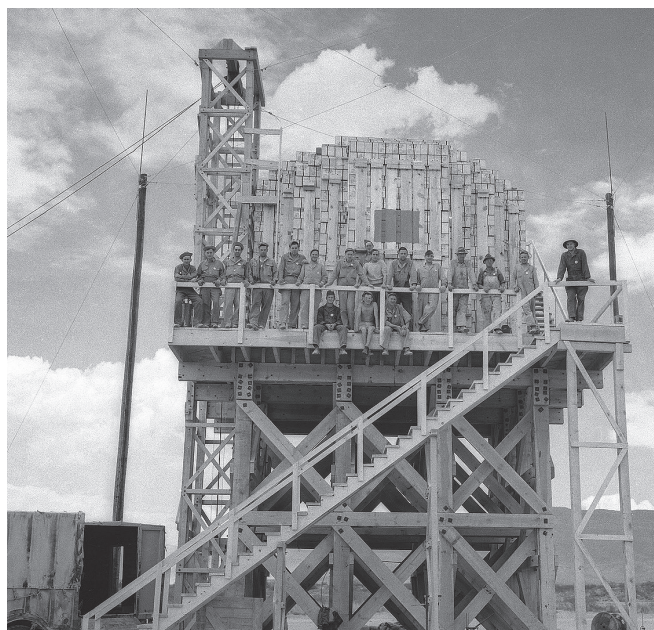
Not the Sensitive Type

Through the decades, much of the Lab's Department of Defense (DoD)-related research has centered on high explosives. This work includes synthesizing thermally stable, hard-to-accidentally-detonate (insensitive) explosives, which make for safer military munitions. (See "A Safer Liftoff," page 18.) In fact, in 1952 Los Alamos developed the first plastic-bonded explosives, which bind explosive powder with plastic to enable better control over the safety and performance characteristics of explosives. After a number of accidents involving nuclear weapons in the 1950s and 1960s (see "Learning from (Near) Disaster," page 16), the call to improve their safety led Los Alamos to develop insensitive high explosives and to patent the manufacturing technique for TATB (triaminotrinitrobenzene), the key ingredient in the insensitive high-explosive charges used to set off nuclear weapons.

The increased need for explosives in the wars following 9/11 and a focus on increased safety prompted the DoD to ramp up its demand for TATB.

Today, TATB is the only insensitive high-explosive molecule approved by the Department of Energy (DOE) for nuclear weapons. Conventional munitions use TATB, as well. By the late 1980s, decreased nuclear weapons production and the end of the Cold War led to a halt in TATB production, but the increased need for explosives in the wars following 9/11 and an ever-present focus on increased explosives safety recently prompted the DoD to ramp up its demand for TATB. Given the Lab's deep background with the material, Los Alamos played a critical role in a nationwide project to start making TATB again over the past 10 years.

In related work, Laboratory scientists are exploring revolutionary new methods of fabricating insensitive high explosives using 3D printing. Also called additive manufacturing, 3D printing allows for the rapid production of insensitive high explosives into complex shapes that would be impossible to make using traditional machining techniques. This technique will also give Los



Los Alamos has been in the explosive science business since the 1940s. The men on this test tower pose in front of the mountain of TNT used in the May 7, 1945, 100-Ton Test—which held the record as the world's largest blast until the Trinity test two months later. (Photo: Los Alamos)

Alamos scientists increased control over the explosives' safety and performance.

Meanwhile, the DOE's Stockpile Stewardship Program has been refurbishing the nation's aging nuclear weapons and the DOE has consistently emphasized continuous safety improvements for explosives used in the stockpile. Using TATB has a big impact on increasing overall nuclear weapons safety.

Lab scientists also tackle practical battlefield challenges, such as researching and testing explosives used in the deadly improvised explosive devices (IEDs) that characterize recent wars. Understanding the nature of these homemade explosives (HMEs) helps the military (and law enforcement) detect, handle, and mitigate them. The Lab also communicates that understanding directly to military Explosive Ordnance Disposal technicians at its Advanced Homemade Explosives Course. (See "The Hurt-Locker School," page 3.)



Emerging Threats and Detecting Explosives

The Laboratory focuses much of its explosive science research on emerging threats and explosive detection. To highlight that focus, in 2015 the Lab established its Explosives Center and also rolled out the Los Alamos Collaboration for Explosives Detection (LACED). Becky Olinger, the center's associate director and program manager at LACED, says new threats cover a broad spectrum beyond countering IEDs. For example, as with the toothpaste bomb threat, the Lab analyzes intelligence information to evaluate the plausibility of potential threat scenarios. "We look at whether these scenarios are a concern and, if so, how do we deal with them?" she says. Threats could include nuclear weapons, HMEs, or conventional explosives. If one seems legitimate, the Laboratory develops a countermeasure.

We are end-to-end, from design and synthesis to supercomputer modeling and testing.

Countermeasures include improving explosives detection. Los Alamos scientists and engineers are doing basic research on new technologies for detecting every conceivable type of explosive in a range of scenarios and then engineering new mitigation technologies for them. That research involves determining the chemical signatures of materials—necessary for developing a detection method—and inventing new methods to neutralize them.

In one example, David Moore of the Laboratory's Explosive Science and Shock Physics division recently led a team that created a radically new technology for detecting explosives from a safe distance. Called ODD-Ex (optimal dynamic detection of explosives), it zaps a suspicious material with a laser and then identifies it by analyzing the reflected light spectrum. Every material has a unique identifying signature of absorbed and reflected light. ODD-Ex combines greater

sensitivity than other related techniques with the ability to filter out interference from dust in the atmosphere, say, or other materials mingled with the explosives that can conceal the material's identity. The high sensitivity enables greater—and thus safer—standoff distance for interrogating a target such as a roadside bomb.

What's Next? The Future of Explosives Science at Los Alamos

No place else can match Los Alamos's suite of capabilities in explosives science and decades of experience: a deep roster of scientists doing research in the field, wide-ranging experience



Los Alamos explosives scientists are developing 3D-printing techniques to rapidly produce insensitive explosives in a wide range of shapes that cannot otherwise be created. Three-dimensional printing also gives increased control over the explosives' safety and performance. (Photo: Los Alamos)

Researchers at Los Alamos heat an explosive compound past its melting point, then pour it from the kettle into an apparatus to do experimental work. Explosives that melt at temperatures well below their ignition points—the temperature at which they blow up—can be safely poured into containers or molds without risk of detonation. (Photos: Los Alamos)



in explosive materials and every kind of detonation, facilities for developing and testing explosives, and expertise in detecting them.

To back up that claim, Explosives Center director Dan Hooks cites metrics such as the larger numbers of explosive tests conducted, papers published, and patents received. He also points to the Lab's exclusive facilities, such as its one-of-a-kind outdoor firing range. (See "Questing for the Holy Grail of High Explosives," page 15.)

"What's unique about Los Alamos in explosives science and research is that we are end-to-end, from design and synthesis to supercomputer modeling and testing, and from detection to characterization," says Olinger. "We cover the full gamut of explosives types, with all the experts on site, and bring real ingenuity to the problem."

We have the tools to see things now that we've only been speculating about for 70 years.

Even with the Laboratory's long, celebrated history of explosives research, Hooks thinks the best work is yet to come. "In explosives, we're in a time of major transition," he says. "We

have the tools to see things now that we've only been speculating about for 70 years, so there will be a generational shift in making new materials, knowing how they will respond, and understanding what drives that response."

Advances in basic science—the theories underpinning research—fundamental diagnostic tools, and computing platforms will enable Lab scientists "to see what's going on in a material—the physics and chemistry—almost in real time," Hooks says. "We'll be able to take a snapshot of picoseconds [millionths of a second] resolved to microns [millionths of a meter] or less. Once we can see something happening, that changes the theory and that changes the model. We'll have a new ability to make things and predict things. These breakthroughs will lead to a fundamental improvement in the safety of rockets and weapons. We're developing the future right now. In 15 to 20 years, it will be a whole new world of explosives science."

Of course, global events will also shape that future. Although the nuclear mission will remain central at Los Alamos and a driver of explosives science, Hooks says, threats such as IEDs and HMEs "will continue to be a challenge in any theater."

No one really knows what the next new threat will look like—or where it will come from. But Los Alamos will be ready to help fend it off. ✦

~Charles C. Poling



Los Alamos conducted more than 400 high-explosive-driven experiments in 2015. (Photo: Los Alamos)

EXPLOSIVE RESULTS

Questing for the Holy Grail of High Explosives



Explosives chemist David Chavez has developed new explosives molecules that offer high energy with enhanced safety—they cannot be detonated by spark, friction, or impact. (Photo: Los Alamos)

The perfect material for detonating nuclear weapons, arming a conventional bomb, mining ore, and even propelling a rocket into space has two seemingly paradoxical characteristics: releasing tremendous energy on demand while resisting accidental detonation and remaining stable for its intended life cycle.

That combination of qualities is the Holy Grail in explosives research, according to Los Alamos scientist David Chavez of the High Explosives Science and Technology group—and he's on a promising quest to find it.

In a recent breakthrough, Chavez invented a molecule that could herald the arrival of a new class of insensitive high explosives. The new compound performs nearly as well as conventional explosives but can't be detonated by a spark, friction, or impact.

Chavez's work exemplifies the sometimes-trying trial-and-error progress of scientific research. Chavez was pursuing his idea for uniquely arranging carbon, hydrogen, nitrogen, and oxygen—the basic building blocks of all explosives—into a novel molecule. Along the way, he stumbled through several failures before hitting on the right configuration of atoms. He found that extensive hydrogen bonding among the molecules created a “glue” strong enough to bind them

but weak enough that an unwanted striking force, spark, or friction can separate the molecules without triggering a detonation. That quality makes them safer to handle and use than conventional explosive materials.

As Chavez's work shows, Los Alamos researchers are constantly deepening their understanding of the basic science underpinning the performance and behavior of explosives (and propellants, too). Those research results then guide new problem solving to support the national security mission of the Laboratory. Developing new explosives with tailored properties, including enhanced safety, has been a primary focus of the Lab's science and engineering efforts since the days of the Manhattan Project. Today, these efforts continue to ensure the viability of the nuclear stockpile, improve conventional explosive weapons, and better position the United States to assess threats from foreign-made explosive materials, according to Chavez.

On a personal note, Chavez adds, the Laboratory environment gives him the opportunity to explore his ideas about explosives: “One of the great things about Los Alamos is having the ability to push the frontiers, to do the new thing that no one's been able to do before.” ✦

~Charles C. Poling

EXPLOSIVE RESULTS

Learning from (Near) Disaster



In 1966, a B-52 collided with a tanker over Palomares, Spain, while refueling. Three of its four hydrogen bombs fell on land, and the fourth fell into the sea, where it was recovered after a lengthy search (see photo on page 17). Two bombs were destroyed when their conventional high explosives detonated; the surviving two bomb casings are on display at the National Atomic Museum in Albuquerque, New Mexico. The incident helped prompt the initiative at Los Alamos to develop insensitive high explosives to prevent future accidental explosions of nuclear weapons. (Photo: Sandia National Laboratories)

Just short of high noon on May 22, 1957, an Air Force B-36 bomber was powering down on its final approach to Kirtland Air Force Base in Albuquerque, New Mexico, completing what should have been a routine flight ferrying a nuclear weapon from a base in Texas. In an instant, all hell broke loose.

A few miles south of the control tower and 1,700 feet off the deck, the bomb bay doors of the huge plane sprang open. In a blink the nuclear bomb plunged earthward, smashing into the ground seconds later with an impact that detonated the high-explosive charges designed to trigger the weapon's nuclear material. The ensuing explosion destroyed the weapon and blasted a crater 12 feet deep and 25 feet wide, hurling debris and bomb fragments a mile away.

As awful as that accident sounds, a nuclear detonation was impossible. For safety, bomb designs in those days centered on a removable capsule of nuclear material carried separately on the plane. The crew would only insert the capsule to arm the weapon in an actual combat operation. This bomb was not armed.

The Kirtland calamity was just one of 32 cited in a 1981 Department of Defense (DoD) report covering the history

of the nuclear program. In a dozen cases, the conventional high explosives unintentionally detonated, and although none tripped a nuclear explosion, they sometimes wreaked destruction and injured or killed crew members and rescuers alike. A 1950 B-29 crash in California claimed 19 lives.

Two tragic, high-profile incidents spewed radioactive material around the landscape and elevated awareness of the risks involved. In January 1966, a B-52 carrying four nuclear weapons collided with its refueling tanker plane at high altitude above Palomares, Spain, knocking both from the air and killing several crew members. The high explosives of two nuclear weapons exploded when they slammed into the ground, scattering plutonium and other nuclear materials up to 500 yards away and contaminating about 650 acres. One bomb whose descent was slowed by a parachute did not detonate, and another disappeared into the Mediterranean Sea; it was recovered more than two months later after the most expensive salvage operation in U.S. Naval history.

Workers hauled off 1,400 tons of soil and vegetation, which were shipped to the United States for disposal, and burned or buried nearby tomato crops that were a key agricultural



In the Palomares incident, a hydrogen bomb vanished into the sea. Sailors recovered the weapon two months later in the most expensive U.S. Navy salvage operation in history. The casing is currently displayed at the National Atomic Museum. (Photo: Open Source)

product in Palomares. But traces of nuclear material remained, as tests starting in the 1990s revealed. After years of wrangling between the two allies over new cleanup details, in October 2015, U.S. Secretary of State John Kerry signed an agreement with Spain to remove, almost 50 years after the accident, additional contaminated soil to an as-yet-unspecified location in the United States.

If the high explosives inside these weapons could be rendered incapable of accidentally detonating, many lives could be saved, property protected, and expensive environmental cleanups prevented.

Two years after the accident over Palomares, a bomber carrying four nuclear weapons crash-landed seven miles short of the runway at Thule Air Base, Greenland, several hundred miles north of the Arctic Circle. The ensuing fire destroyed all the weapons and scattered plutonium and uranium. Although intense cold and the total darkness of Arctic winter hampered the cleanup, crews ultimately removed 237,000 cubic feet of contaminated ice and debris.

If the high explosives inside these weapons could be rendered incapable of accidentally detonating, many lives could be saved, property protected, and expensive environmental cleanups prevented. As weapons designers looked for ways to increase the safety of nuclear weapons, they turned to developing safer high explosives for triggering the implosion of a nuclear blast.

Fire and impact cannot start a nuclear explosion—only the high explosives precisely detonating in their carefully designed configuration within the warhead can do that. But as the DoD's report reveals, accidentally detonating high explosives caused tremendous problems all on their own.

The solution was achieved at Los Alamos through development of less sensitive high explosives. Los Alamos developed manufacturing and formulation methods for the explosive TATB (triaminotrinitrobenzene) for triggering nuclear weapons (and for use in conventional ordnance). TATB burns but does not explode when it's heated, and does not react even when struck by bullets or shrapnel. Deliberately detonating this unique material requires a well-engineered initiation system.

Los Alamos began researching insensitive high explosives in the 1950s. Based on that expertise, the Laboratory played a key role in refining TATB, patenting the TATB manufacturing process, and becoming the first national lab to use a TATB composition in nuclear weapons.

From the beginning, the skills of Los Alamos weapons designers at making sure their nuclear weapons were safe meant that none of these weapons unintentionally detonated, even after the most horrific accidents. Even so, servicemen lost their lives in these accidents. The advances in explosives science at the Lab means that today, the risk of accidental detonation and death is more remote than ever. ✦

~Charles C. Poling

EXPLOSIVE RESULTS

A Safer Liftoff

An innovative rocket-fuel system taps a novel source of power and breakthrough engineering to deliver high-energy thrust with improved safety.

On a broad mesquite plain in central New Mexico, a small crew fits a metal cylinder into a rocket the size of a baseball bat, then slips the rocket onto guide rods on a platform. A “Los Alamos” logo on the fuselage certifies this launch as official science by the world-famous national laboratory, not a weekend outing with the kids.

Bryce Tappan and a handful of scientists, engineers, and students from Los Alamos National Laboratory and New Mexico Tech stand back as another crew member handles a control box set on a folding table. He counts down, “Three, two, one, zero!” The rocket issues a loud *pssshhhhhewwwweeee!* and whisks into the cobalt sky, the cylinder trailing a stream of gases and tilting toward horizontal as it soars to its apogee.

The small group cheers, perhaps a little more vigorously than one might expect, but that’s because this 41-inch rocket just proved that a novel fuel invented by Tappan and others at the Lab actually works.

Powerful, safe, and potentially powerful enough to launch a full-sized spacecraft, the breakthrough segregated-fuel-oxidizer system, called IsoFOX, enables a new era in propellants. For rockets, missiles, and satellites the fuel is a “humongous safety improvement,” according to Dan Hooks, director of the Los Alamos Explosives Center. Hooks explains that missiles carry “a huge tonnage of propellant,” which multiplies the risk of their detonable fuels exploding accidentally, “so any safety improvement is tremendous.”

From Failure to Breakthrough

Ironically, Tappan, who came to the Lab first as an undergraduate in 1996, then returned as a postdoctoral researcher in 2003, stumbled onto this propellant in the wake of a disappointment. He was studying an energetic material called TAGzT (triaminoguanidinium azotetrazolate) and related compounds. (Energetic materials store chemical energy, which is a useful characteristic for making explosives, propellants, or fuels.) It had failed miserably as an explosive.

“For more than 20 years, Los Alamos had been experimenting with synthesizing high-nitrogen materials for use in energetic

materials,” Tappan explains. “High nitrogen content is interesting in explosives because it can reduce the amount of oxygen needed to burn the fuel atoms in the molecule, making an oxygen balance easier to achieve.” Managing the amount of oxygen in a fuel helps tune its safety characteristics. The nitrogen makes for a higher-energy-density system that works much like an automobile efficiently burning gasoline. Tappan was experimenting with these high-nitrogen/high-hydrogen materials, which contain little or no oxygen, for their applications to explosives.

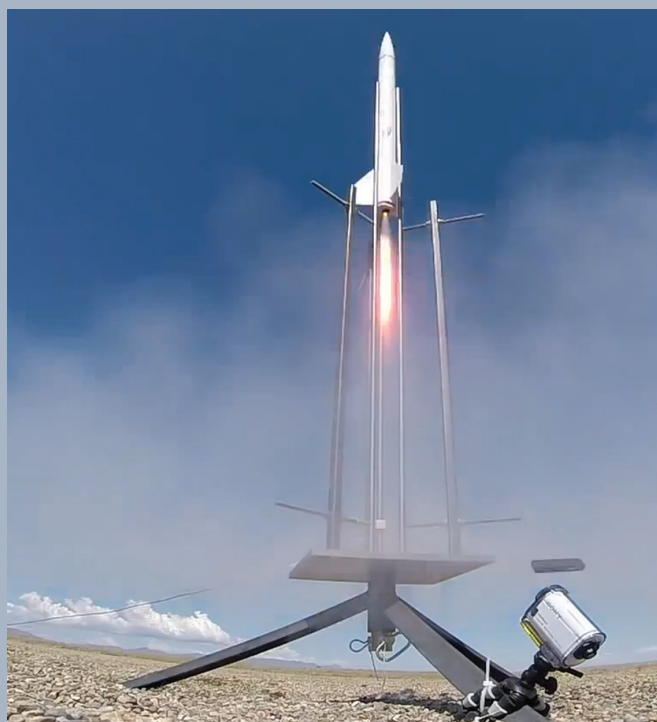
In his first large-scale test with TAGzT, the material didn’t detonate.

“I thought, this sucks,” Tappan recalls with a laugh. “Then I thought, wow, this could be an important discovery as a propellant ingredient. Non-detonable materials that combust well are good for propellants and bad for explosives.” TAGzT—and the novel fuel that Tappan would later develop from it—“doesn’t detonate at all. It just burns.” That property opened up the potential for a new kind of rocket fuel several years later, when a collaborator from Penn State University came to Tappan for oxidizer pellets to use with a liquid fuel. Tappan had a better idea, based on his research: use a high-nitrogen/high-hydrogen energetic material.

“There was nothing else out there like it in the research literature,” he says.

Actually, It Is Rocket Science

In a slow-motion video of the test showing the simultaneous launch of Tappan’s rocket beside a conventionally fueled twin, Tappan’s rocket ignites and vanishes from the frame as the other lumbers up. It’s a jackrabbit leaving a tortoise in the dust.



The next-generation rocket? Los Alamos scientists recently tested a powerful new rocket fuel and motor that are safer because the fuel is kept separate from its oxidizer. The new rocket motor and fuel outperformed commercial rockets in thrust with at least twice the velocity. (Photo: Los Alamos)

“The actual rocket launch was definitely tense,” Tappan says. “If you go to YouTube and search ‘rocket motor failure,’ you’ll get thousands of videos, and these are rockets that had who-knows-how-many millions of dollars poured into them. It’s never a given the rocket is going to work because the tests in a laboratory don’t necessarily translate to an actual successful launch. So it was a very exciting moment to demonstrate something we had been working on for a couple years.” The flight data showed the Los Alamos rocket motors outperformed the commercial rocket motors in thrust with at least twice the velocity.

“The main goal of this project is to get something that offers very high safety in a completely non-detonable system without an energy penalty,” Tappan explains, meaning the material would still provide plenty of propulsion. “Typically, when you look at something that’s high performance, it’s not a safe material. We’re trying to break that performance versus sensitivity curve and make a rocket propellant that’s high-energy and high-performance as well as very safe.”

Tappan explains that the “enabling technology” involves “physically separating the energetic fuel material and a solid oxidizer.” A typical solid rocket propellant keeps the fuel and oxidizer together, with potentially dangerous and explosive results. The Lab’s segregated-fuel-oxidizer system, IsoFOX, keeps the fuel and oxidizer apart because the initial stage of ignition does not require oxygen. The high-nitrogen/high-hydrogen energetic material decomposes when ignited, creating a fuel that flows into the separate secondary section of the rocket containing the solid oxidizer. There the fuel combusts with oxygen released from a reaction with the oxidizer, and full propulsion is achieved—fast! This design dramatically reduces the chance of accidental detonation. It’s also completely insensitive to shock, meaning a sharp impact won’t blow up the rocket.

What's Next

Becky Olinger, associate director of the Los Alamos Explosives Center, sums up Tappan’s breakthrough: “Tappan’s rocket technology provides a safer alternative to propellants without compromising performance.” The project began under Laboratory Directed Research and Development funding, which supports high-risk, potentially high-payoff research in promising directions. The next steps are refining the fuel system and exploring industrial partnerships to commercialize it.

Tappan intends to follow two tracks: scaling up the system to larger motors and miniaturizing it for use on satellites. As an on-board satellite fuel system, IsoFOX addresses concerns about the risk of an explosion destroying the craft in space. Such a system could shift a satellite between orbital planes or bring it back into Earth’s atmosphere when its mission is complete.

One day, Tappan suggests, IsoFOX might even power a small satellite to the moon. That’s a lofty target for a material that once fizzled in a lab test. ✨

~Charles C. Poling

Chamber 1,
High-N/High-H Fuel

Fore Nozzle

Chamber 2, Oxidizer

View the flight tests:

youtube.com/watch?v=wwEVFVfA50&feature=youtu.be

Aft Nozzle

Fig. 1